Politecnico di Torino

ENERGETICS

AMMIN/DENERG - Optimal Planning and Dispatch of Distributed Renewable Energy Sources for Grid-Constrained and Demand-Intensive Power Systems

Funded By	Dipartimento DENERG Politecnico di TORINO [P.iva/CF:00518460019]
Supervisor	LANZINI ANDREA - andrea.lanzini@polito.it
Contact	
Context of the research activity	The rapid deployment of distributed renewable energy sources, energy storage systems, and large electricity consumers is reshaping the planning and operation of power systems. Distribution and transmission networks are increasingly exposed to congestion, voltage violations, thermal overloads, reverse power flows, and uncertainty in both generation and demand. These issues are amplified by the growth of demand-intensive loads such as data centres, electric vehicle charging hubs, industrial electrification, e-fuels production, and flexible commercial loads. Recent analyses highlight that data centres are becoming systemically relevant electricity consumers, with software-driven load profiles, high connection-capacity requirements, and potential impacts on grid security. ENTSO-E notes that access to electricity is now one of the main bottlenecks for data centre development, with connection queues ranging from years to more than a decade in constrained areas; the same report identifies hosting-capacity transparency and flexible connection agreements as key planning instruments. The IEA also projects strong growth in data-centre electricity demand, increasing the need to coordinate new demand with renewable generation, grid reinforcements, and flexibility resources. At present, many planning approaches still treat generation siting, load connection, grid reinforcement, and storage deployment as separate problems. This creates a gap between network planning studies and actual operational feasibility. A node may appear attractive for renewable generation because of resource availability, land availability, or permitting, but it may be technically unsuitable due to voltage or thermal constraints. Conversely, locations suitable for large loads such as data centres may not be aligned with renewable availability, storage potential, or existing grid capacity. A further gap concerns the limited transparency of grid hosting capacity. Developers, system operators, and regulators need tools able to identify where new distributed renewable energy sources can be connected with minimal congestion impact, where flexible demand can be located, and where co-location of generation, storage, and demand can reduce grid stress. Current tools often lack an integrated simulation framework combining

	network constraints, renewable generation profiles, demand evolution, storage operation, and flexibility provision. The research will address this gap by developing an optimal planning and dispatch framework for distributed renewable energy resources and demand-intensive loads, with particular attention to congestion management, hosting capacity assessment, and grid-supporting flexibility.

Objectives	The main objective of the research is to develop a transparent, simulation-based decision-support tool for the optimal siting, sizing, and dispatch of distributed renewable energy sources, energy storage systems, and large flexible loads under transmission and distribution grid constraints. The research will pursue four specific objectives. First, the activity will develop a grid-aware hosting-capacity methodology to identify the most suitable network nodes for connecting new renewable generators and demand-intensive loads. The tool will evaluate technical feasibility through power-flow and optimal-power-flow simulations, considering voltage limits, line and transformer thermal limits, losses, congestion risk, and future demand scenarios. Second, the research will formulate an optimisation model for the co-siting and co-dispatch of distributed renewables, storage, and flexible loads. The model will consider short- and medium-term storage technologies, including Li-ion batteries and redox-flow batteries, accounting for power and energy limits, efficiency, cycling constraints, degradation, and service availability. The optimisation will seek to maximise renewable integration and connection feasibility while minimising congestion, curtailment, operational costs, and reinforcement needs. Third, the activity will integrate flexibility services into the planning framework. Demand-intensive loads, such as data centres, will not be modelled only as passive consumers, but as controllable resources able to provide flexibility through load modulation, workload shifting, cooling optimisation, and storage-backed operation. This aligns with the emerging view that data centres and similar loads can evolve from grid-safe consumers to grid-supporting assets, provided that the appropriate control architecture and market or regulatory signals are in place. Fourth, the research will implement a multi-scenario simulation environment combining grid models, renewable generation profiles, demand-growth forecasts, and flexibility-resource models. The framework will test different planning cases, including high-renewable penetration, concentrated load growth, constrained-grid areas, storage co-location, and flexible connection agreements. The element going beyond the State of the Art is the integration of planning and dispatch in a single transparent tool. Instead of separately identifying renewable sites, load-connection points, and storage locations, the proposed framework will assess their combined impact on the grid. The tool will provide locational signals for both generation and demand, helping answer questions such as: where should new distributed renewable sources be connected; where can large loads be feasibly located; when is co-location with storage beneficial; and how much flexibility is required to avoid network violations? The expected outcome is a methodology that supports system operators, planners, and developers in making coordinated and technically robust decisions for future grid expansion and renewable integration.

	The development of the research activity requires interdisciplinary competencies in power systems, optimisation, renewable energy modelling, and energy-storage technologies.

Skills and competencies for the development of the activity	A strong foundation in electrical power systems is required, including power-flow analysis, optimal power flow, grid congestion assessment, voltage regulation, thermal constraints, hosting capacity evaluation, and transmission-distribution interaction. Competence in modelling distributed renewable energy sources, especially photovoltaic and wind generation, is also necessary to represent variable generation profiles and curtailment risks. The research also requires advanced optimisation skills, including linear, mixed-integer, nonlinear, stochastic, and multi-period optimisation methods. These methods will be used to formulate siting, sizing, and dispatch problems under technical, economic, and operational constraints. Programming skills in Python, MATLAB, Julia, or similar environments will be essential, together with experience using grid-simulation tools such as pandapower, OpenDSS, PowerFactory, MATPOWER, or equivalent software. Specific knowledge of energy storage systems is also required, including battery modelling, degradation, charge-discharge strategies, grid services, and the different operational characteristics of Li-ion and redox-flow batteries. In addition, the activity requires understanding of demand-side flexibility, particularly for large loads such as data centres, including load shifting, backup systems, cooling demand, and flexible connection schemes. Finally, the research will benefit from competencies in data analysis, scenario generation, renewable forecasting, techno-economic assessment, and regulatory knowledge related to grid connection, congestion management, flexibility markets, and renewable integration. These skills will enable the development of a robust planning tool that is technically accurate, transparent, and applicable to real-world grid-planning challenges.